Cree Power – Sept 2014 HMW Direct-Drive Motor Workshop

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Power products commercial roadmap for SiC from 2012-2020 – Jeff Casady

Power products rel data & pricing forecasts for 650V-15kV SiC power modules, MOSFETs & diodes – John Palmour

www.cree.com

Section

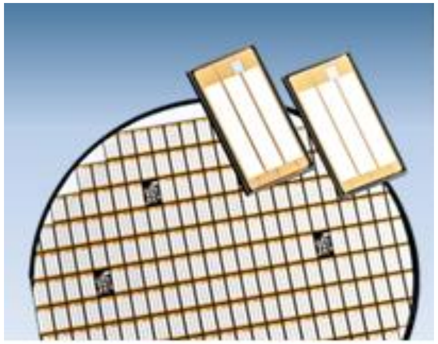
Power Products Commercial Roadmap from 2012-2020

Cree SiC MOSFET Portfolio Beginning in 2011

>13 products and growing

1200V MOSFETs (Bare Die)

- CPM2-1200-0025 (25mΩ; 60A)
- CPM2-1200-0040 (40mΩ; 40A)
- CPM2-1200-0080 (80mΩ; 20A)
- CPM2-1200-0160 (160mΩ; 10A)



1200V MOSFETs (TO-247)

- C2M0025120D (25mΩ; 60A)
- C2M0040120D (40mΩ; 40A)
- C2M0080120D (80mΩ; 20A)
- C2M0160120D (160mΩ;10A)
- C2M0280120D (280mΩ; 7A)

1700V MOSFETs

New 1700 V MOSFETs needed for PV inverters with 1.0-1.5 kV bus voltages

- C2M1000170D (1Ω, 3.0A) TO-247
- *CPM2-1700-0040 (40mΩ; 50A) Bare Die*

Cree All-SiC Power Module Portfolio Beginning in 2012

> 7 products and growing

50 mm Platform Half-Bridge Configuration

- CAS100H12AM1 (1200V, 100A)
- XAS125H12AM2 (1200V, 125A)
- XAS125H17AM2 (1700V, 125A)

45 mm Platform 6-Pack Configuration

- CCS050M12CM2 (1200V, 50A 6-pk)
- CCS020M12CM2 (1200V, 20A 6-pk)

62 mm Platform Half-Bridge Configuration

- CAS300M12BM2 (1200V, 300A)
- CAS300M17BM2 (1700V, 250A)

1700V ½ bridge released!

Cree 1700V, 8mΩ, ½ bridge power module available NOW

Full commercial release – September 2014

Available globally – Digikey, Mouser, Richardson/Arrow (right), … ~ $850 single unit

Gate drivers, app notes available

2 channel; 1.2/1.7 kV 62 mm module gate driver direct mount

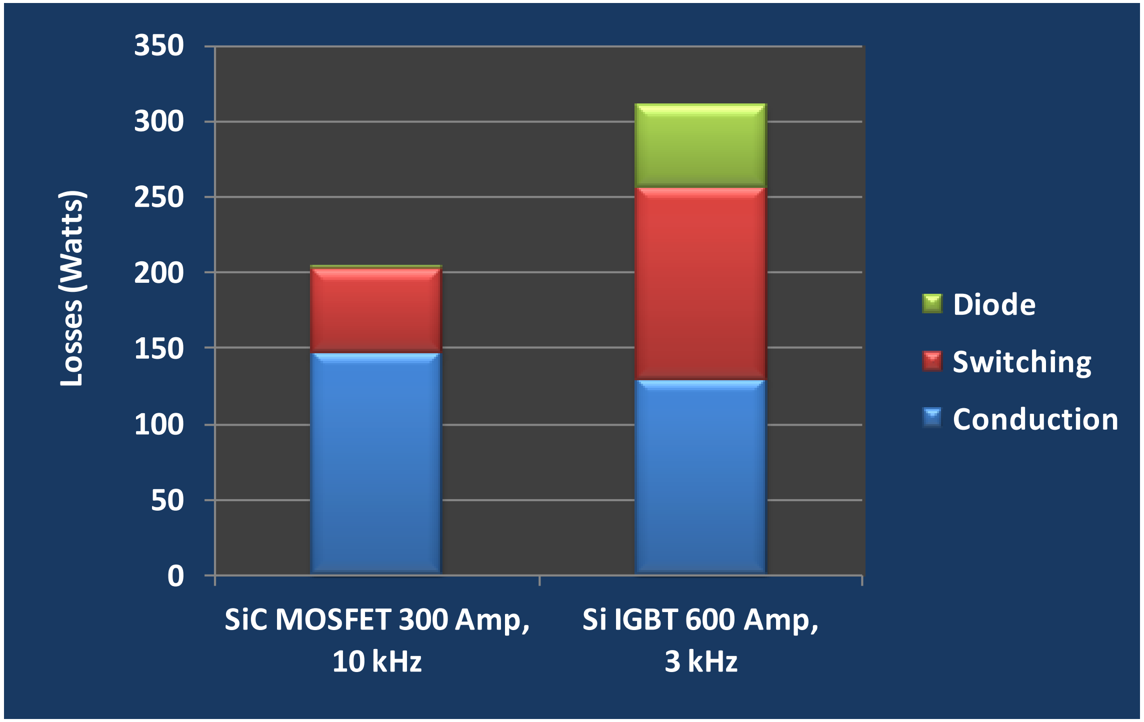
Section –

SiC MOSFET Roadmap

SiC current ratings are much less than Si

Si Amps are *not* SiC Amps

300 Amp SiC More Capable than 600 Amp Si IGBTs!



- **System cost reduction of 20% using 1200V SiC**
  - **Increased frequency reduces size and weight of magnetics**
  - **Lower losses reduce system cooling requirements**
  - **Amperage rating for SiC less than half required for Si IGBTs**

SiC voltage ratings are much less than Si?

Si Volts are *not* SiC Volts

6.5 kV Si IGBT used for 3.6 kV drives (100 cosmic ray FIT rate)

4.5 kV SiC MOSFET used for 3.6 kV line?

10 kV SiC MOSFET used for 7.2 kV?

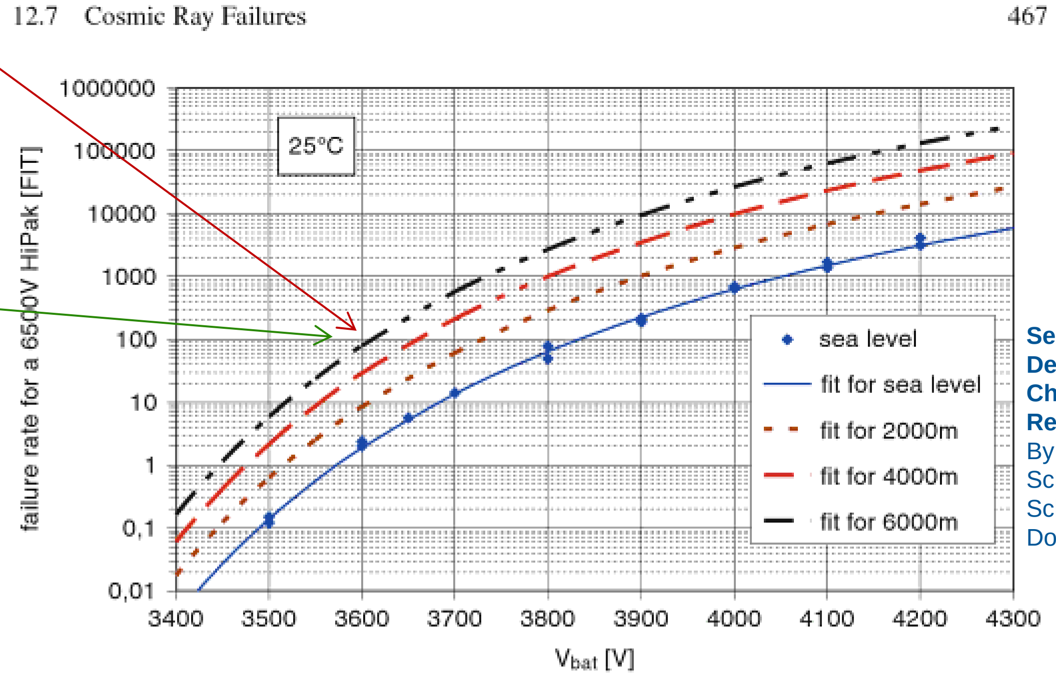


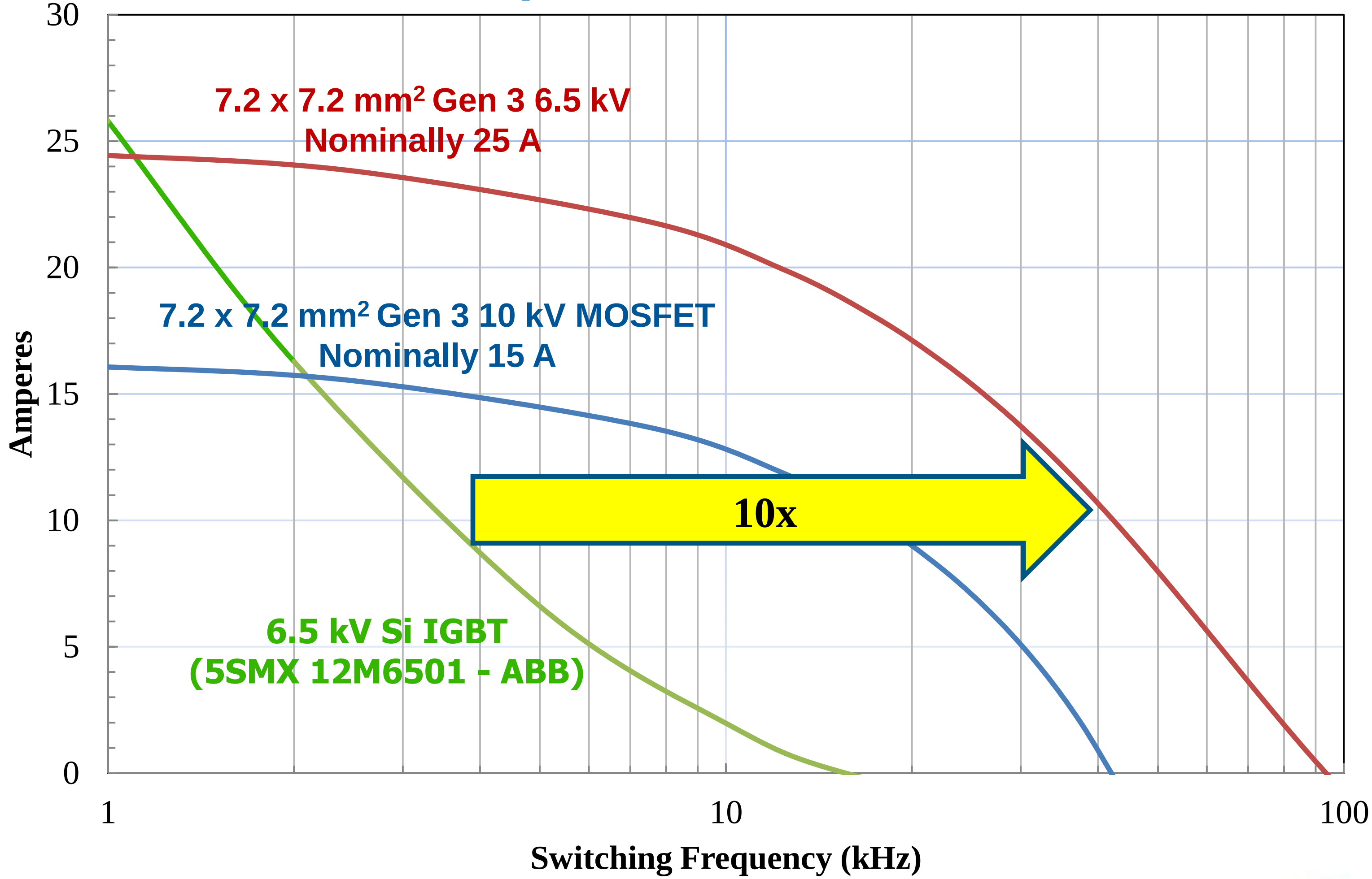
Fig. 12.49 Cosmic ray failure rate at $T = 25°C$ for the 6.5 kV IGBT module 5SNA0600G650100 from ABB. Figure from [Kam04]

Semiconductor Power Devices: Physics, Characteristics, Reliability
By Josef Lutz, Heinrich Schlangenotto, Uwe Scheuermann, Rik De Doncker

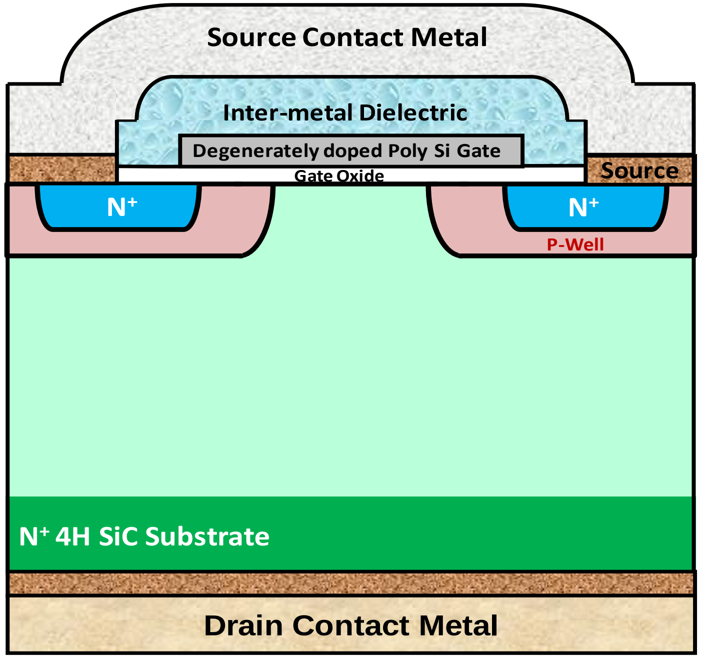
- **Medium Voltage SiC MOSFET roadmap must respond to application**
  - **10X higher switching frequency, lower thermal dissipation possible**
  - **Cosmic ray, other reliability metrics may be 100X better**
  - **All requirements, eg. short circuit, surge must be understood**

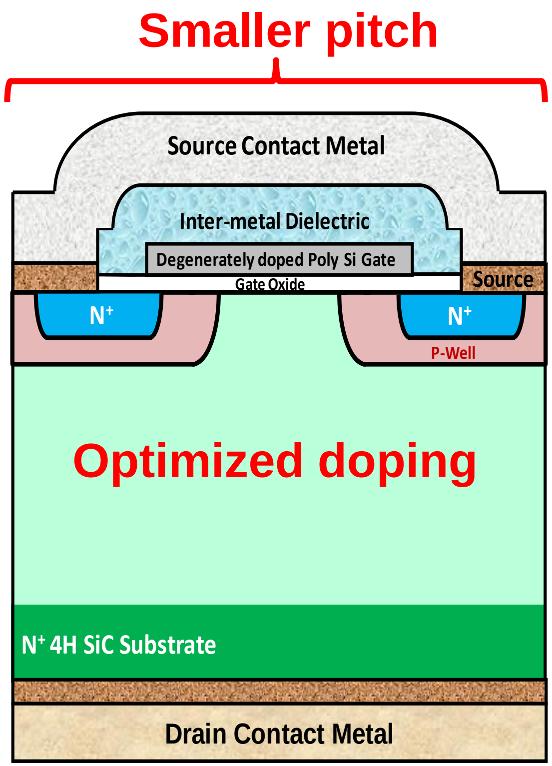
10X higher switching for SiC MOSFET than Si IGBT

Dramatic Reduction in System Weight and Complexity compared to Silicon



3rd Generation SiC MOSFETs





Gen 2 DMOS

Commercially released in 2013

Gen 3 DMOS

Same high reliability DMOS Structure, but optimized to dramatically reduce die size

3.3 kV, 40 mΩ, "40 A" MOSFET Engineering Samples

PRELIMINARY

CREE

3.3kV

Z-FET™ Silicon Carbide MOSFET

N-Channel Enhancement Mode

Bare Die

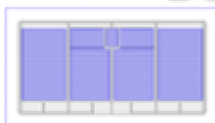
V_{DS}	= 3300 V
I_D (T_C=90°C)	= 45 A
R_{DS}(25°C)	= 40 mΩ

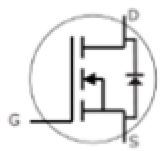
Features

- Industry Leading $R_{DS(on)}$
- High Speed Switching
- Temperature-Independent Switching
- Easy to Parallel
- Simple to Drive
- Lead-Free

Package

Bare Die





Benefits

- Higher System Efficiency
- High Temperature Operation
- High Switching Frequency Operation
- Reduced Cooling Requirements
- Avalanche Ruggedness

Applications

- Solar Inverters
- Motor Drives
- EV Chargers
- UPS

Part Number	Package	Marking
	Die	NA

Maximum Ratings (T_C = 25°C unless otherwise specified)

Symbol	Parameter	Value	Unit	Test Conditions	Notes
I_D	Continuous Drain Current	[redacted]			
I_{Dpulse}	Pulsed Drain Current				
E_{AS}	Single Pulse Avalanche Energy				
E_{AR}	Repetitive Avalanche Energy				
I_{AR}	Repetitive Avalanche Current				
V_{GS}	Gate – Source Voltage				
P_{tot}	Maximum Power Dissipation				
T_J, T_{stg}	Operating Junction and Storage Temperature Range				
T_L	Solder Temperature				

Note:
1. Assumes a thermal resistance junction to case of = 0.3 °C/W.

Electrical Characteristics (T_C = 25°C unless otherwise specified)

Available under NDA

Symbol	Parameter	Value Min	Value Typ	Value Max	Unit	Test Conditions	Notes
$V_{(BR)DSS}$	Drain – Source Breakdown Voltage	[redacted]					
$V_{GS(th)}$	Gate Threshold Voltage						
I_{DSS}	Zero Gate Voltage Drain Current						
I_{GSS}	Gate-Source Leakage Current						
$R_{DS(on)}$	Drain-Source On-State Resistance						
g_{fs}	Transconductance						
C_{iss}	Input Capacitance						
C_{oss}	Output Capacitance						
C_{rss}	Reverse Transfer Capacitance						
R_G	Internal Gate Resistance						
E_{ON}	Turn-On Switching Loss						
E_{OFF}	Turn-Off Switching Loss						

Mechanical Dimensions

Parameter		Unit
Die Dimensions (L x W)	[redacted]	mm
Exposed Source Pad Metal Dimensions		mm
Gate Pad Dimensions		mm
Chip Thickness		µm
Frontside (Source) metallization (Al)		µm
Frontside (Gate) metallization (Al)		µm
Backside (Drain) metallization (Ni/Ag)		µm

10 kV, 300 mΩ, “20 A” MOSFET Engineering Samples

PRELIMINARY

CREE

CPM3-10000-0270

Z-FET™ Silicon Carbide MOSFET

N-Channel Enhancement Mode

Bare Die or Engineering Sample Package

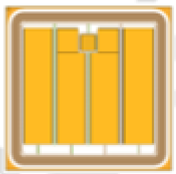
V_{DS}	= 10 kV
I_D (25°C)	= 30 A
R_{DS}(25°C)	= 270 mΩ

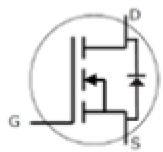
Features

- Industry Leading $R_{DS(on)}$
- High Speed Switching
- Temperature-Independent Switching
- Easy to Parallel
- Simple to Drive
- Lead-Free

Package

Bare Die





Benefits

- Higher System Efficiency
- High Temperature Operation
- High Switching Frequency Operation
- Reduced Cooling Requirements
- Avalanche Ruggedness

Applications

- Grid tied Solar Inverters
- Medium Voltage Motor Drives
- Power Distribution in Data Centers and Factories
- Railway Applications

Part Number	Package	Marking
	Die	NA

Maximum Ratings (T_C = 25°C unless otherwise specified)

Symbol	Parameter	Value	Unit	Test Conditions	Note
I_D	Continuous Drain Current				
I_{Dpulse}	Pulsed Drain Current				
E_{AS}	Single Pulse Avalanche Energy				
E_{AR}	Repetitive Avalanche Energy				
I_{AR}	Repetitive Avalanche Current				
V_{GS}	Gate – Source Voltage				
P_{tot}	Maximum Power Dissipation				
T_J, T_{stg}	Operating Junction and Storage Temperature Range				
T_L	Solder Temperature	260	°C	1.6mm (0.063") from case for 10 sec	

Electrical Characteristics (T_C = 25°C unless otherwise specified)

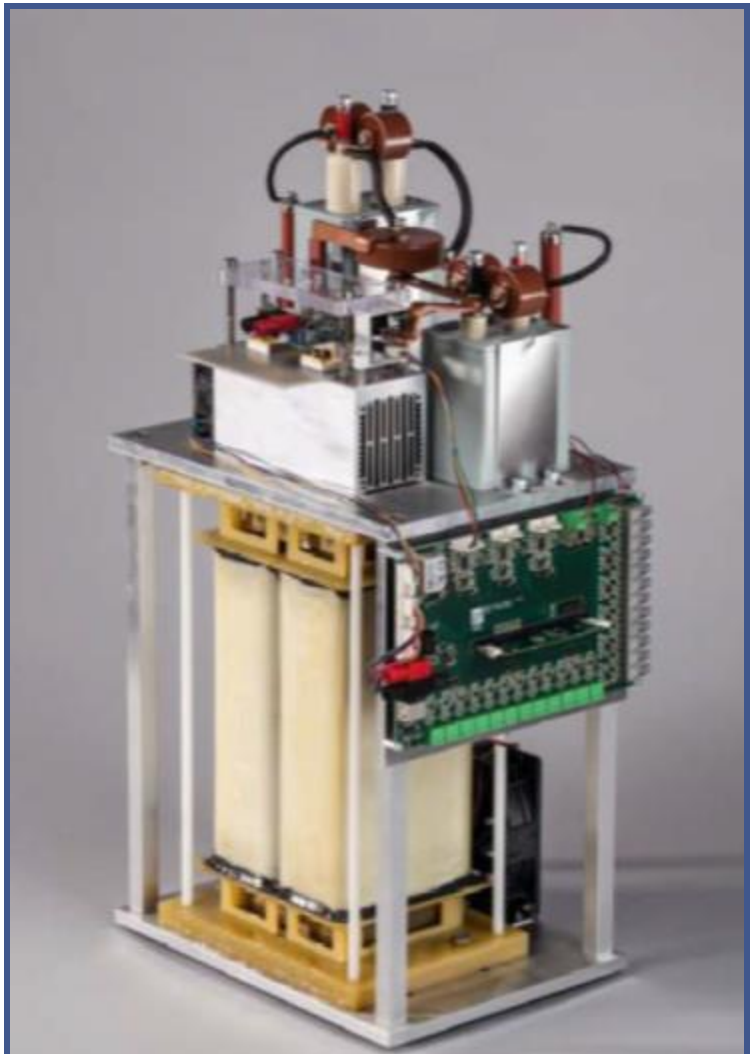
Available under NDA

Symbol	Parameter	Value Min	Value Typ	Value Max	Unit	Test Conditions	Notes
$V_{(BR)DSS}$	Drain – Source Breakdown Voltage						
$V_{GS(th)}$	Gate Threshold Voltage						
I_{DSS}	Zero Gate Voltage Drain Current						
I_{GSS}	Gate-Source Leakage Current						
$R_{DS(on)}$	Drain-Source On-State Resistance						
g_{fs}	Transconductance						
C_{iss}	Input Capacitance						
C_{oss}	Output Capacitance						
C_{rss}	Reverse Transfer Capacitance						
R_G	Internal Gate Resistance						
E_{ON}	Turn-On Switching Loss						
E_{OFF}	Turn-Off Switching Loss						

Mechanical Dimensions

Parameter		Unit
Die Dimensions (L x W)		mm
Exposed Source Pad Metal Dimensions		mm
Gate Pad Dimensions		mm
Chip Thickness		µm
Frontside (Source) metallization (Al)		µm
Frontside (Gate) metallization (Al)		µm
Backside (Drain) metallization (Ni/Ag)		µm

10 kV SiC MOSFETs in Boost Converter (Fraunhofer ISE)



Box is 36 cm x 30 cm

Efficient, "transformer-less" power distribution to medium voltage grid

- Fraunhofer DC-DC converter used 10kV SiC MOSFETs from Cree
- 30 kW DC voltage converter with 3.5 kV input voltage, 8.5 kV output voltage, 98.5% efficient
- 8kHz switching frequency 15X higher than possible with conventional silicon devices in the same voltage range.

Fraunhofer ISE

A Highly Efficient DC-DC-Converter for Medium-Voltage Applications
Jürgen Thoma, David Chilachava, Dirk Kranzer
ENERGYCON 2014 • May 13-16, 2014 • Dubrovnik, Croatia

Section

Power products rel data & pricing forecasts for 650V-15kV SiC power modules, MOSFETs & diodes

Section

Power Products Reliability Data

Proven Reliability with Industry-Leading Standards

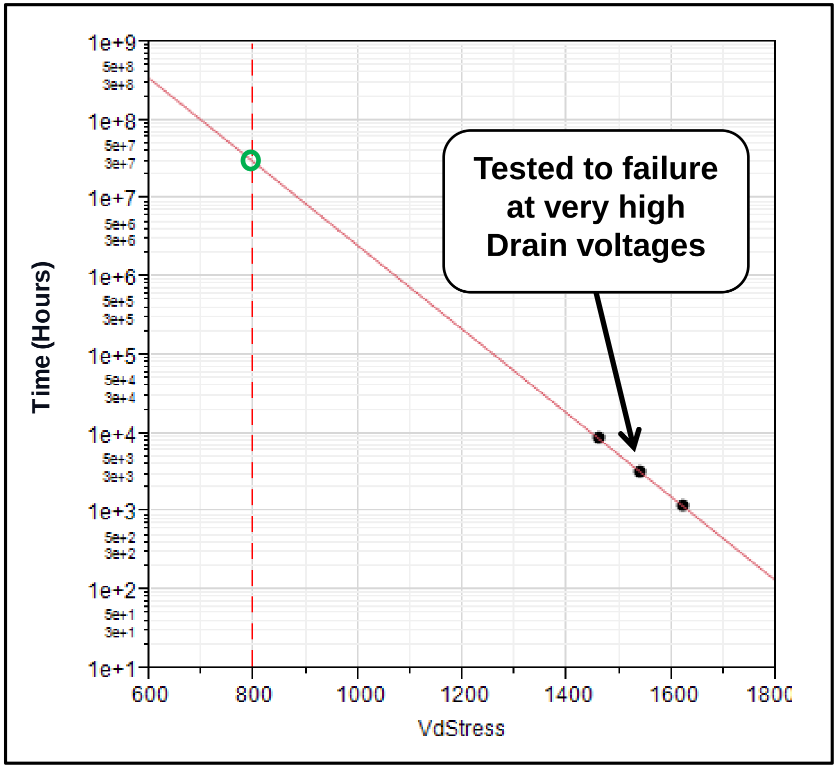
Cree Field Failure Rate Data since Jan. 2004 through Mar. 2014

Product	Device Hours	FIT (fails/billion hrs)
CSDxxx60	426,000,000,000	0.05
C2Dxx120	146,00,000,000	0.54
C3Dxxx60	367,000,000,000	0.02
C4Dxxx120	26,700,000,000	0.04
SiC MOSFET	1,140,000,000	3.5
Total	972 Billion	0.12

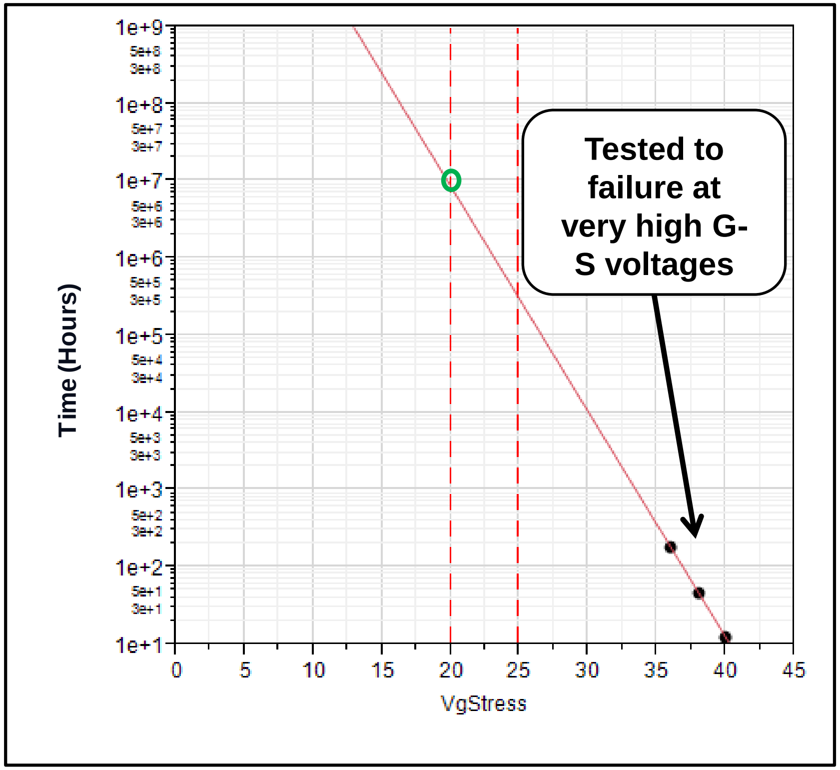
- 0.12 FIT rate is 10 times lower than the typical silicon
- SiC diodes first released in 2001
- SiC MOSFETs first released in 2011

Reliability Meets All Commercial and Military Requirements

Accelerated HTRB Testing at 150° C



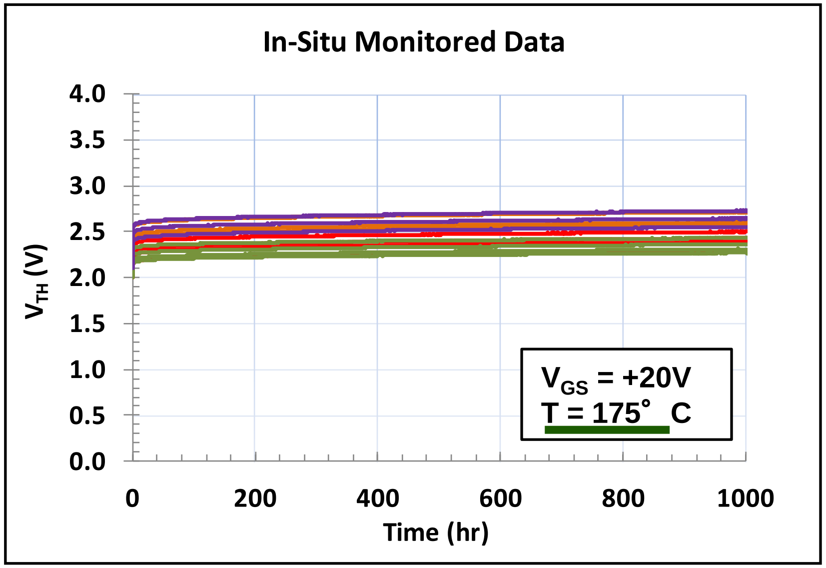
Accelerated TDDB Testing at 150° C



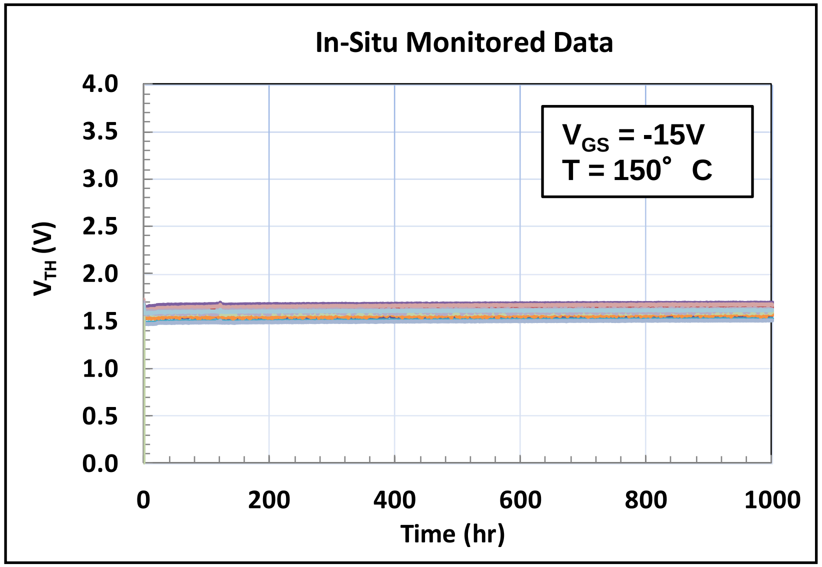
- **MOSFETs have extrapolated MTTF of 30 million hours**
- **Gate oxides have extrapolated MTTF of 8 million hours at +20V continuous**

C2M V_{TH} Stability at High Temperature, +/- DC Bias

Positive Bias Accelerated at 175° C



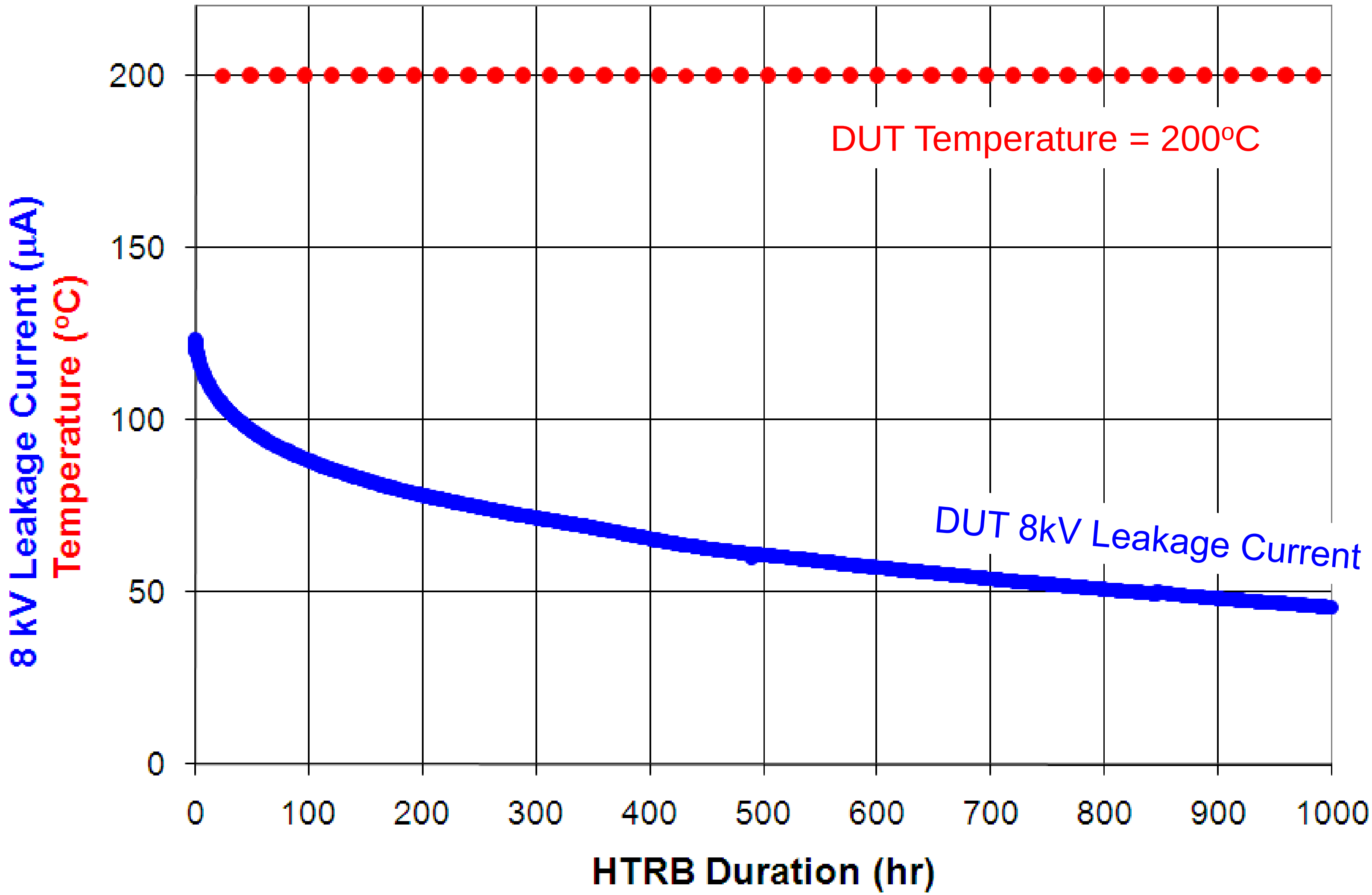
Negative Bias Accelerated at -15V



- **Extremely stable for 1,000 hours under positive and negative bias**
  - **Accelerated beyond data sheet to see any measurable change**
  - **Average shift under positive bias: ΔV_{TH} = 0.06 V, $\Delta R_{DS\text{-}ON}$ = 0.1 mΩ**
  - **Average shift under negative bias: ΔV_{TH} = 0.01 V, $\Delta R_{DS\text{-}ON}$ = 3.2 mΩ**

MOSFET Off-State Blocking Reliability

8 kV, 200^{o}C, 1000 hr HTRB of 10 kV SiC MOSFET



Section

Pricing Forecasts

Vertical integration in the power semiconductor industry

Global **SiC** Power ***Chip*** Supplier Rankings (2013)

2013 Rank	Supplier	HQ Location
1	***Cree***	***USA***
2	Infineon	Germany
3	Mitsubishi	Japan
4	ROHM	Japan
5	ST Micro	FR-IT

Top 5 suppliers (95% of market) with US supplier (Cree) No. 1 shown on left

Global **Si** *and* **SiC** ***Power Module*** Market Share (2011)

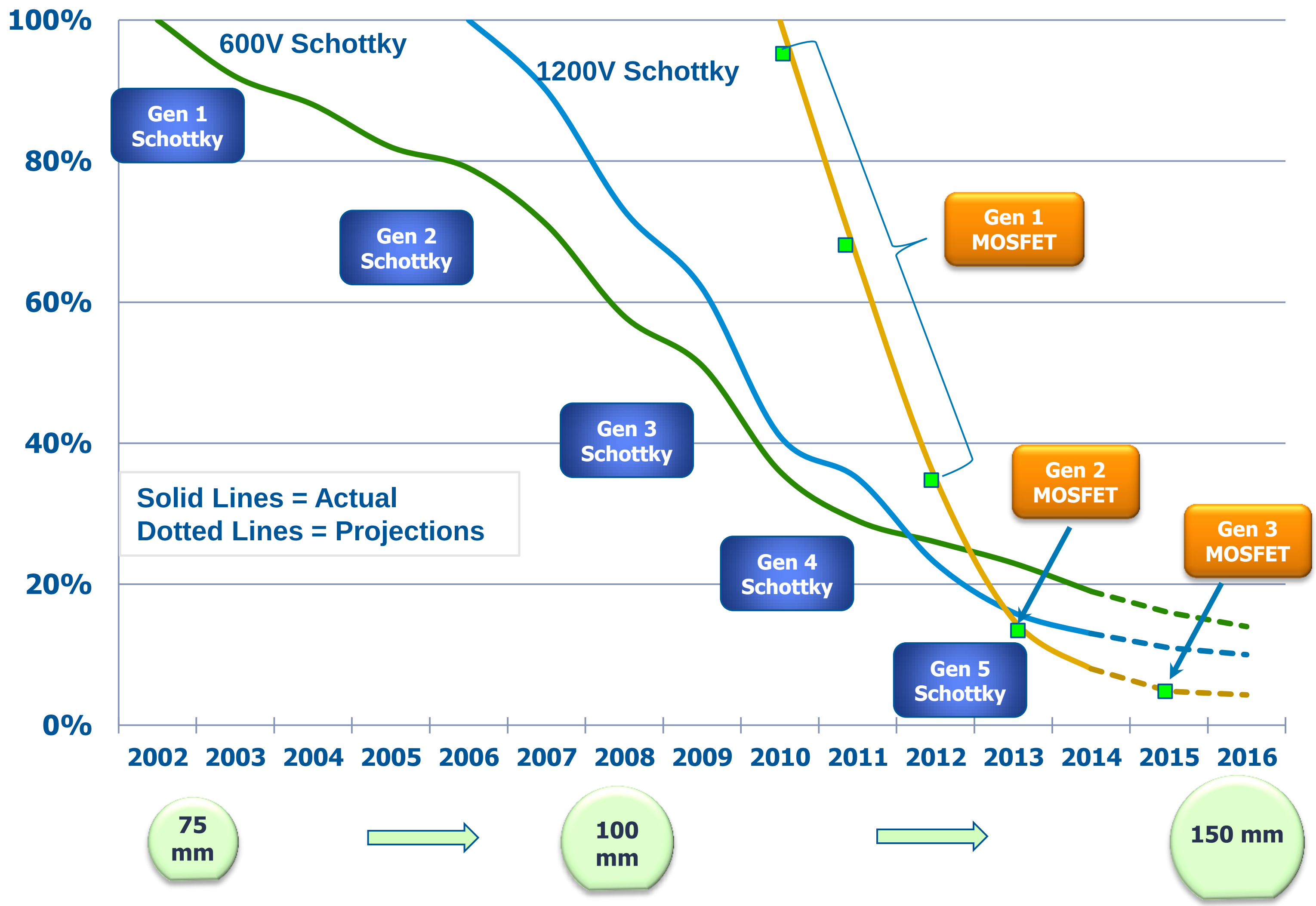
2013 Rank	Supplier	HQ Location	
1	Mitsubishi (inc Powerex)	Japan	**Vertical, captive chip supply**
2	Infineon	Germany	**Vertical, captive chip supply**
3	Fuji	Japan	**Vertical, captive chip supply**
4	Semikron	Germany	**Foundry module vendor**
5	Hitachi and Sanyo (tie)	Japan	**Vertical and foundry mix**

SiC Leadership – Leveraging Vertical Integration & Scale

150mm wafer capability in RTP facility
> $40M invested in RTP fab capacity expansion over 3 years

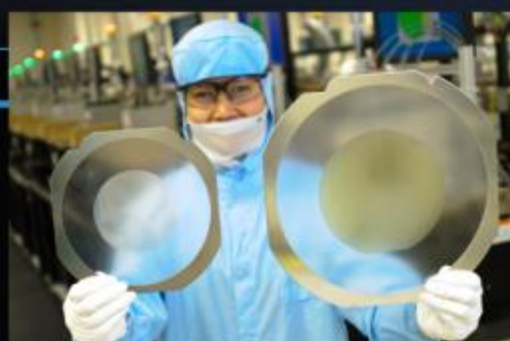
- **Vertically integrated $1.65 B business:**
  - **Virtually all revenue based on SiC substrates**
  - **Unmatched command of supply chain from raw materials to finished products** (including power and RF devices, LEDs, light bulbs and fixtures)
  - **Avoiding margin stacking in supply chain provides attractive cost structure**

Cost reduction from volume and device refinement



Cree has the global footprint & world-class distribution network to deliver SiC products wherever you need them.

Cree is the leader in Silicon Carbide power semiconductors.



Cree is one of world's fastest-growing power semiconductor manufacturers.

Cree has excellent capitalization.

Cree is vertically integrated—for an efficient supply chain and product traceability.

Cree has the technology roadmap for improved SiC production and cost reduction.